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Preliminary Note on the Nature of the Electrical Discharges of the Electric Eel, *Electrophorus electricus* (Linnaeus).

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(Text-figure 1).

Although the Electric Eel has been known to science since 1729 and has been the subject of much speculation and an enormous literature in respect to the nature of the electrical phenomena exhibited, there is still a considerable discrepancy between the voltages observed by different investigators and a great deal yet to be learned about the nature of the generation and discharge of these voltages. Since the development of the Cathode Ray Oscillograph, we think that more accurate observations may be made than any heretofore, and present this short report of our findings to date.

Preliminary observations into the voltage developed were made by means of a device of resistances and neon pips designed and built for us by Mr. H. M. Ferree of the General Electric Vapor Lamp Company. This indicated the voltages in steps ranging from 85 to 150; 150-170; 170-300; 200-450 and 450-600. The eels used in this preliminary investigation varied in size from 11½ inches to 7 feet 10 inches and readings were taken both in and out of water. In no single instance was a voltage beyond the 170-300 range recorded. This is not in accord with voltages reported by Eilenfeld.[1] Some of the fish were tested immediately upon arrival and some after they had been in aquaria for several years, being fed, during that time, on a variety of living fishes which necessitated the continued use of electrical discharges on the part of the eel if it were to eat. Table I gives the respective sizes of the various eels tested.

Small eels were found to be more suitable for investigations with the oscillograph, which was a Radio Corporation of America Cathode Ray oscillograph type T M V-122-B. In the most satisfactory observations the eel under test was removed from the water, dried, and laid in an insulating trough two inches wide, in which were set transverse tinned copper wires one inch apart. By means of dial switches any two of these wires could be connected to one pair of deflecting plates of the oscillograph. With the timing circuit connected to the other pair of deflecting plates the variation of the voltage in time could be observed.

Two types of discharge were clearly distinguished.[2] In each type the voltage between two points on the eel rose to a maximum and returned to zero. The anterior part of the eel was always positive with respect to the posterior *and no reversal of voltage* was observed. The curve showing the variation of voltage with time appeared symmetrical and the shape suggested a Gaussian errors curve. The duration of one discharge was of the

[1] EILENFELD, Walter: Ueber den Reflexschlag von *Gymnotus electricus* nach Untersuchungen mit dem Oszillographen Beiträge zur Physiologie, Berlin, 1927, Band 3, pp. 195-198.
[2] This is in accord with those reported by Eilenfeld.

order of 10^{-3} second. The two types of discharge differed strikingly in potential variation along the eel and in the maximum voltage attained. Observations on both types made on an eel 11.5 inches long with 55 cc. displacement in water are shown on the figure. The abscissa shows distances measured along the eel from head to tail. The difference in ordinate between any two points shows the peak voltage developed between the points on the eel corresponding to the associated values of the abscissa. It will be noticed that in the principal discharge the potential is uniform over the anterior two inches and the posterior two inches of the eel. In the less vigorous or secondary discharge the potential is uniform over the anterior four inches and the posterior two inches of the eel. The origins of the Large Electric Organs and Hunter's Organs were two inches posterior to the snout and the origins of the Bundles of Sachs were about No. 7 on the figure.

The peak voltage observed in either type of discharge between any two points was not repeated uniformly. In successive discharges of the principal type deviations from the mean of 25 per cent. were observed. The voltages developed also diminished as the eel was kept a longer time out of water. The contrast between the two types of discharge, as shown in the figure, is probably exaggerated by this latter cause, the observations on the secondary discharge having been commenced after the observations on the primary discharge were completed, and indeed after the maximum voltage of the primary discharge had been observed to fall from its initial value around 200 volts to about 135 volts.

In this respect it might be as well to note that there is a wide variation in the rate of fatigue between different animals and the same animal in different conditions. This has been observed but not recorded by one of us over several years' work with many eels of all sizes.

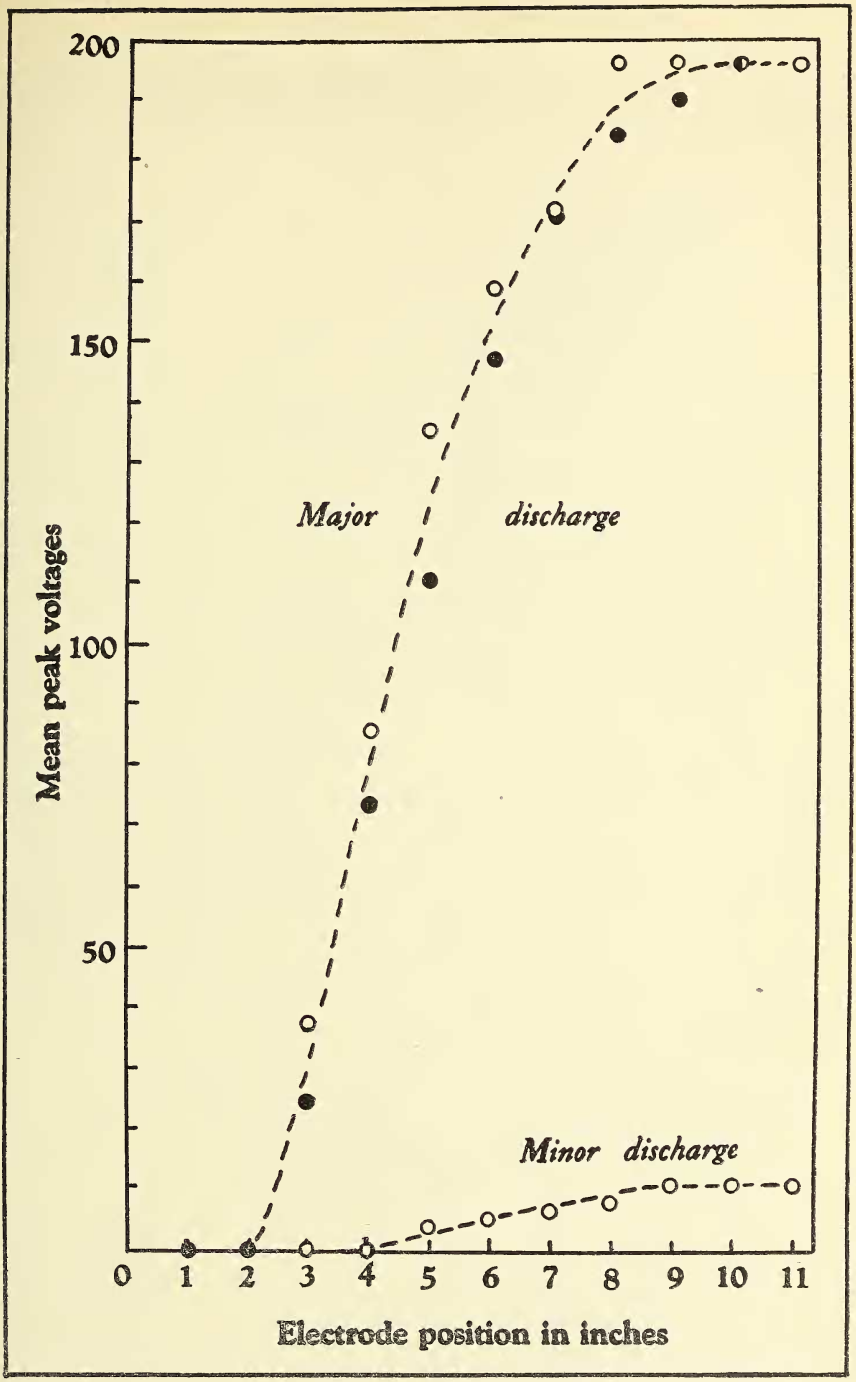
Observations of another eel of about the same size showed a principal discharge of about 200 volts accompanied by a secondary discharge of about 20 volts, and observations of a third eel 15½ inches long showed a principal discharge of about 145 volts accompanied by a secondary discharge of about 30 volts.

Another difference observed between the principal and secondary discharges was that while the secondary discharges follow one another apparently at random intervals of time, the principal discharges commonly occur in pairs with a rather regular interval which is several times the duration of one discharge.

Some observations suggested a third type of discharge with a peak voltage around one volt, but the disturbances to which the oscillograph is subject with the high amplification required to show such a discharge render its existence uncertain, as yet.

No satisfactory measurements were made of the power developed in the discharges. Some rough observations on an eel about 12 inches long give a value of the order of 3 watts for the power developed externally at the peak of the principal discharge when the eel is in the water to which it is accustomed.

To determine whether the change in potential begins simultaneously at all points along the length of the eel or whether there is a progressive potential pulse from head to tail, the timing circuit of the oscillograph was cut off and one plate of each deflecting pair was connected to one point on the eel somewhat behind the middle and the other plates were connected near the head and tail respectively. If there were no time lag, the trace on the oscillograph screen would be a straight line, since the two voltages giving rise to the vertical and horizontal displacements of the beam of cathode rays would have a ratio constant in time. The trace observed was, on the contrary, a narrow loop, roughly elliptical. This seems to indicate that the potential pulse is propagated along the eel in a time of the same order as, or less than, the duration of the pulse between two points. Since



Text-figure 1.

Graph showing mean peak voltages at 1-inch intervals on Eel No. 2. The open circles on the major discharge curve represent voltage readings taken from head to tail; the black dots represent readings taken in the reverse order. In the minor discharge, no differences were observed in readings from either direction.

the eel was about one foot in length, the speed of the pulse would appear to be of the order of 1,000 feet per second. Such a speed is higher than those commonly found in the propagation of electrical impulses along nerves.

TABLE I.

Size of Eels on which measurements were made.

3	eels	7	feet	long		in water only.
3	"	7	"	3	inches	
1	"	7	"	9	"	
1	"	7	"	10	"	
1	"	3	"	4	"	both in and out of water.
1	"	3	"	1	"	
1	"	2	"	10	"	
1	"	1	"	3½	"	
2	"			11½	"	

TABLE II.

Eel No. 2. Length 11½ inches.

Mean peak voltage of major discharge.

TEST No. 1			TEST No. 2			
Electrode A	Electrode B	Voltage	Electrode B	Electrode A	Voltage	Voltage reckoned from 0
0	2	x	11	0	196	0
	3	37		1	196	0
	4	86		2	196	0
	5	135		3	172	24
	6	159		4	122	74
	7	172		5	86	110
	8	196		6	49	147
	9	196		7	25	171
	10	196		8	12	184
	11	196		9	6	190
				10	x	196

TEST No. 3					TEST No. 4 Mean peak voltage of minor discharge			
Electrode A	Electrode B	Observed voltage	Corrected voltage†	Voltage from curve	Electrode A	Electrode B	Voltage	Voltage reckoned from 0
0	11	135	196	196	0	11	10.5	0
0	10	135	196	196	1		10.5	0
1	10	135	196	196	2		10.5	0
1	9	135	196	196	3		10.5	0
2	9	135	196	196	4		10.5	0
2	8	122	177	189	5		6.6	3.9
3	8	110	160	159	6		5.3	5.2
3	7	98	142	145	7		4.0	6.5
3	6	74	107	125	8		2.7	7.8
4	6	49	71	73	9		x	10.5
4	5	37	54	42				

†—Observed voltage x $\frac{196}{135}$ to correct for fatigue.

x—voltage too small to read.

Tests were made consecutively with five minute rest intervals between each.